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MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LVII. SUPPLEMENTARY NUMBER, 1897. No. 9

Personality in Measurements of Photographs for the Astrographic Catalogue, at the University Observatory, Oxford. By H. H. Turner, M.A., F.R.S., Savilian Professor.

1. In the measurement of the plates for the Astrographic Catalogue at this observatory special care has been taken to eliminate systematic error of bisection. Every plate is measured twice in reversed positions (turned in its own plane through 180°), and the two measures of each star are compared. We thus obtain :—

(*a*) A check on mistakes of comparatively large amount.

(*b*) Information as to error of bisection, which affects the two measures of any star in opposite directions, and thus appears doubled in the difference.

(*c*) The elimination of the error of bisection by taking the mean of the two measures.

(*d*) Information as to the probable error of a single measure.

The main object of the present note is to show how little photographic measures are affected by error of bisection. The micrometer used here is described in *Monthly Notices*, vol. lv. p. 102, and has a scale in the focus of the eyepiece divided to $3''\cdot0$ and reading by estimation to $0''\cdot3$. It does not profess the greatest possible accuracy, but in the present paper it is shown

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that the systematic errors are very small indeed ; and experience has proved that the accidental errors are much smaller than might be expected.

2. The main points of the paper may be summarised as follows, under the several paragraphs :—

§ 4. The general personality or error of bisection for a given measurer and instrument rarely exceeds 0″·15, or half the estimated unit. Its mean value, irrespective of sign, is 0″·09.

§ 5. The measurer and his instrument must be taken together. A change in either means a new personality.

§ 6. The personality remains sensibly constant for some months at least.

§ 7. The probable error of a determination of personality from a single plate (of about 200 stars) is less than ±0″·05.

§ 8. The variation of personality with stellar magnitude is very small ; and what there is can be detected and eliminated by reversing the plate. Hence we may look to photographic measures with confidence as a means of ridding star-places of systematic error depending on magnitude of the star.

§ 10. The probable error of a single measure is about ±0″·24, and of the mean of two, ±0″·17 ; thus the results satisfy the conditions imposed by the Comité Permanent last May.

3. *Method of Reversal.*—It may be well to explain here the exact method adopted in reversing the plate. At the Royal Observatory, Greenwich, I believe both the plate and the measuring scale are rotated through 180°, so that, though the directions of measurement (both right and left and up and down) are reversed to the observer's eye, the figures recording the star's position in both coordinates are approximately the same as before. The figures printed on the eye-piece scale are read upside down, but this is a mere detail ; the estimated fraction of a division is now to the right instead of the left, or up instead of down, the same actual division being in use. At Oxford, on the other hand, the scale is not reversed, only the plate, so that if the measured coordinates of a star were in the direct position (denoted D), say 3·057 and 17·304, then in the reversed position (denoted R) they are approximately 22·943 and 8·696—*i.e.*, the differences of the former from 26·000, which is the length of a side of the measuring reseau. Suppose 22·941 and 8·697 are actually recorded in the R position. Then before comparison with the D measures, the R measures are subtracted from 26·000, giving 3·059 and 17·303 respectively. The differences of these from the D measures are then tabulated as +·002 and −·001 respectively, the errors of bisection being half these amounts. The method adopted at Greenwich obviates this subtraction ; but it is considered that the greater independence of the readings at Oxford is worth the extra trouble. Since two entirely different divisions of the eye-piece scale are employed at Oxford, there will also be a slight decrease of apparent accuracy, owing to the errors of scale

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divisions; but, as in other similar cases, this increase of accidental error is accompanied by a decrease of systematic error.

4. *General Personality for Different Measurers.*—To give an idea in the first instance of the kind of quantity under discussion, the following table shows the mean error of bisection (*i.e., half* the mean difference R – D) for all stars on a considerable number of plates for different observers and different instruments. For the way in which the probable errors of these quantities shown in column six have been calculated see § 7. They depend, of course, on the number of plates, shown in column five.

Table I.

Mean Error of Bisection in Photographic Measures.

Measurer.	Inst.	Error of Bisection. Coord. x.	Coord. y.	No. of Plates.	Prob. Error of Mean.
		″	″		″
B.	α	+0·12	+0·24	17	±0·01
B.	β	+0·20	−0·03	7	±0·02
F.	β	−0·06	+0·13	36	±0·01
H.	α	−0·02	+0·02	12	±0·02
H.	β	−0·13	+0·07	10	±0·02
C.	α	−0·18	0·00	16	±0·02
C.	β	−0·12	+0·04	4	±0·03
M. H.	α	−0·09	+0·27	6	±0·02
M.	μ	−0·03	+0·06	16	±0·02

Considering that the single star places are only read off by estimation to 0″·3, these quantities are very small, although well defined, as the probable errors of the last column show. But only in four cases out of eighteen do they exceed 0″·15 (the half of a unit in the last place), and even for a plate measured by several different measurers it seems unprofitable to apply them. Only a few plates have been measured at Oxford by different measurers; for the great majority the same measurer has measured it throughout, and thus the personality is completely eliminated. The few exceptions, measured by miscellaneous measurers at the beginning of the work, have all been re-measured by a single measurer, and thus the mean of the two sets is only affected with half such personalities as shown above.

5. *Change of Instrument.*—If the measurer changes to another instrument he must be treated as a new measurer. This is exemplified especially in the case of B. in the above table, who changed from +0″·12 to +0″·20 in x, and from +0″·24 to −0″·03 in y, when he changed from one measuring machine to another (of the same pattern). To test the reality of the change

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he measured first with α, then with β, and then with α again; and it was found that he returned at once to his old personality with α. On the other hand, changing from α to β did not produce nearly such an effect on H. and C. There is nothing gained by analysing the effects of the measurer and instrument separately. They must be taken together, and if either is changed we must expect a new result.

6. *Progressive Change with Time.*—The question whether these personalities are fairly constant may be answered in the affirmative. The Oxford measurers were all new to the work, and from the analogy of transit personal-equations we should expect any change to be most marked at the beginning of the work. But at present no sensible changes have appeared. Take, for instance, F., who has a long series of plates with the same machine. Dividing his measures into groups in order of date we find

No. of Plates.	Mean Dates of Measures. D	R	x	y
			″	″
10	1896 Sept. 9	1896 Nov. 16	−·07	+·10
10	1896 Oct. 15	1896 Nov. 3	−·13	+·20
10	1897 Jan. 21	1897 Jan. 29	+·01	+·13
6	1897 Apr. 5	1897 Apr. 24	−·07	+·10

The accordance between the first and last of the series being curiously complete. It is needless to multiply instances, as the work has as yet only been going on for some months, and changes may make their appearance in the future. Meantime it seems probable that they will develop gradually, if at all.

7. *Probable Error of a Determination.*—We can thus treat a series of plates measured by the same measurer with the same instrument as homogeneous, and available without further modification for determination of probable error. Different series give *mean* errors for a single plate varying between ±0″·04 and ±0″·07. Thus, without making an elaborate computation, we may assume the *probable* error of a determination from a single plate to be at least as small as ±0″·06. Dividing by the square root of the number of plates we get the results shown in the sixth column of Table I.

For illustration, the best and the worst of the different series at present available are given below. Each result refers to a whole plate, and thus depends on the measurement of (roughly speaking) 200 stars. No attempt has been made to assign different weights to the plates according to the number of stars.

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SERIES I.

Measurer M. Inst. μ.
Coordinate y.

Plate.	Error of Bisection.	Diff. from Mean.
	″	″
653	+·07	+·01
883	+·11	+·05
380	+·09	+·03
375	+·03	−·03
376	+·03	−·03
374	+·03	−·03
368	+·02	−·04
362	+·01	−·05
377	+·16	+·10
383	+·14	+·08
384	·00	−·06
784	+·10	+·04
785	+·03	−·03
250	+·08	+·02
268	+·06	·00
269	+·03	−·03
Mean	+·06	±·04

SERIES II.

Measurer H. Inst. β.
Coordinate y.

Plate.	Error of Bisection.	Diff. from Mean.
	″	″
749	·00	−·08
750	+·05	−·03
889	−·09	−·17
412	+·10	+·02
414	·00	−·08
787	+·08	·00
788	+·14	+·06
791	+·12	+·04
300	+·30	+·22
628	+·09	+·01
Mean	+·08	±·07

The Series I. was made by a measurer* who had had considerable practice in micrometric measurement at the telescope. Series II. are the first measures of an entirely inexperienced measurer; is much shorter, and shows some evidence of progressive change, by allowing for which we could reduce the ±″·07 to ±″·06 at least. Other series fall between these extremes, and the probable error for a single plate is most likely less than ±″·05. The estimates in column six of Table I. are thus fairly liberal.

8. *Variation with Stellar Magnitude.*—We now come to a more important question. Is this error of bisection the same for all stars? In the case of transit-personal-equations attention has of late years been called to the fact that they vary with the brightness of the star observed. The photographic method seems to offer a means of checking such errors in meridian observations, and it has been shown by Mr. Hinks (*Monthly Notices*, vol. lvii. p. 473) how it can be used to good purpose in this way. But are measures on photographs entirely free from errors of this kind? The expedient of reversing the photograph enables us to eliminate them, even if existent; but it is more comfortable to be assured of their non-existence if possible, or at least of their smallness.

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* Mr. T. J. Moore, of the Leeds Astronomical Society. It is to be remarked to his credit that micrometer μ is only a wooden model, which he thus used to very good purpose. He now has a properly made metal micrometer.

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To investigate this point the measures on a number of plates have been divided into groups according to the size of disc of the star measured. The size of disc is a rough (see § 9) indication of the magnitude, nevertheless good enough for our purpose; and the results are exhibited in tabular form below.

TABLE II.

Variation of Bisection-error with Stellar Magnitude.

Measurer.	Coordinate.	Error of Bisection in Group					No. of Stars in Group				
		I.	II.	III.	IV.	V.	I.	II.	III.	IV.	V.
F.	*x*	−″·02	−″·08	−″·08	+″·08	+″·06	453	537	216	171	18
H.	*x*	+·02	−·08	−·21	−·27	−·20	833	410	165	138	8
C.	*x*	−·18	−·23	−·17	−·08	−·29	397	402	149	146	20
M.	*x*	−·02	−·02	+·05	−·06	−·05	258	338	140	143	15
F.	*y*	+·24	+·15	·00	+·21	+·27	454	548	219	171	18
H.	*y*	+·05	+·11	+·08	+·08	−·17	849	395	172	153	8
C.	*y*	−·03	−·02	+·05	+·06	+·12	406	407	148	150	15
M.	*y*	+·06	+·08	+·02	+·09	+·03	245	334	137	144	13

The groups are arranged as follows :—

Group	I.	Estimated diameter of disc	0″·3 to 3″·0
,,	II.	,, ,, ,,	3·3 ,, 4·5
,,	III.	,, ,, ,,	4·8 ,, 6·0
,,	IV.	,, ,, ,,	6·3 ,, 12·0
,,	V.	,, ,, ,,	over 12·0

Group I. thus comprises all the faint stars, of about magnitude 11, and Group V. the bright stars of magnitude 8 and brighter.

I think it will be clear from the above table that there is nothing to be anxious about in such measures. Some measurers show an almost complete independence of stellar magnitude, as for instance M., and the largest range shown is 0″·29 (H. IV. − H. I.). It is to be remembered that even these small differences, if real, can easily be detected and also eliminated by reversal of the plate; and the hope that the photographic method offers us an escape from this troublesome error seems well grounded.

9. *The Determination of Magnitudes.*—The size of disc has been described in the preceding paragraph as a *rough* estimation of magnitude. This point cannot here be fully examined, but one or two remarks may be made. Firstly, the diameters of the discs are estimated very differently by different measurers. If all measurers estimated them alike, we should expect to find the numbers of stars in the different groups proportional to one another. But, on looking at the above Table II., it is seen that H. makes

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Group I. contain twice as many as Group II.; while others make Group II. the larger. Secondly, it is especially the fainter stars which are differently estimated. Those who have tried such estimations will recognise that for the faint stars the intensity of the patch as well as its size should be taken into account, but it is difficult to do so.

It is not without precedent that the accurate photometry of the stars should lag behind the determination of their positions; for this has been the case all along. Positions are not only easier to determine, but more pressingly needed. As an illustration, I may refer to a paper (in No. 411 of the *Astronomical Journal*, received as I am writing), by Professor Howe on Comet 1896, VI., wherein he requires the places of 173 comparison stars. The collection of these from various sources has doubtless involved much labour, which will be considerably reduced when such measures of position as those above considered are complete. But Professor Howe does not *want* the magnitudes of the stars; he does not even mention them in the paper.

10. *Probable Error of the Measures.*—When a plate has been measured in the two positions, and the differences of the measures formed, each difference is one of the numbers -5, -4, -3, -2, -1, 0 $+1$, $+2$, $+3$, $+4$, $+5$; the unit being $0^{\rm r}{\cdot}001$ or $0''{\cdot}3$. Cases where the difference exceeds 5 $(=1''{\cdot}5)$ are considered as due to some mistake, and *both* measures are repeated. If there is a clear mistake of say ${}^{\rm r}{\cdot}010$ in one of the measures, it is altered or rejected: otherwise the mean of the four measures is taken. For the normal differences between -5 and $+5$ $(-1''{\cdot}5$ and $+1''{\cdot}5)$ the number in each group is counted, giving results as follows (for an imaginary plate):—

Plate 2386, *Measurer X.*

	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5
x	1	4	17	48	35	12	4	4	2	0	0
y	0	0	4	1	10	28	37	19	12	3	1

These numbers give us both the personalities above considered, and also the probable error of a measure. Thus the mean difference in the x coordinate is:

$$(-5\times1-4\times4-3\times17-\&\text{c.})/127=-185/127=-{\cdot}0015.$$

and in the y coordinate:

$$(-3\times4-2\times1-1\times10+1\times37+\&\text{c.})/115=+104/115=+{\cdot}0009,$$

giving personalities of half this amount, or $-0''{\cdot}22$ in x and $+0''{\cdot}14$ in y.

To find the probable error, we should subtract this mean from each difference and sum the residuals without regard to sign or their squares. But an approximate result may be obtained with less labour by considering the mean coincident with the residual which occurs most frequently, which in the above hypothetical

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case would be -2 for x and $+1$ for y. (The actual mean for y is very near $+1$; but for x it lies midway between -1 and -2, and the assumption is thus of maximum inaccuracy.) We thus consider 0 written over the 48, ± 1 over the 17 and 35, ± 2 over the 4 and 12, and so on. And the mean error in x is:

$$\pm\{(17+35)\times 1+(4+12)\times 2+(1+4)\times 3+4\times 2+2\times 3\}/127=\pm 113/127$$
$$=\pm\,^{\mathrm{r}}{\cdot}0009 \text{ or } \pm 0''{\cdot}27,$$

and the probable error of a single measure is taken as:

$$\pm 0''{\cdot}27\times\frac{1}{\sqrt{2}}\times{\cdot}85=\pm 0''{\cdot}15.$$

Similarly in y the mean error is:

$$\pm\{(28+19)\times 1+(10+12)\times 2+(1+3)\times 3+(4+1)\times 4\}/115=123/115$$
$$=\pm{\cdot}0011 \text{ or } \pm 0''{\cdot}33,$$

and the probable error of a single measure is taken as $\pm 0''{\cdot}19$.

Calculated in this way we obtain the following probable errors for the different measurers:—

Measurer.	Inst.	Mean Date.	x	y	No. Stars.
B.	α	1896 May 16	±0″·16	±0″·20	730
B.	α	1896 Oct. 27	±0·22	±0·22	960
B.	β	1897 Jan. 10	±0·20	±0·16	1076
F.	β	1896 Oct. 12	±0·27	±0·27	700
F.	β	1897 Apr. 10	±0·20	±0·24	430
H.	α	1896 Nov. 19	±0·27	±0·29	820
H.	α	1897 Feb. 20	±0·25	±0·19	900
H.	β	1896 Oct. 7	±0·27	±0·26	830
C.	α	1896 Nov. 10	±0·29	±0·31	370
C.	α	1897 Jan. 20	±0·27	±0·20	1010
C.	β	1897 Apr. 11	±0·27	±0·24	660
C.	β	1897 July 8	±0·26	±0·25	1940
M. H.	α	1897 July 11	±0·26	±0·29	680
M.	μ	1896 Nov. 4	±0·20	±0·20	430
M.	μ	1897 May 31	±0·17	±0·20	2000
		General Mean ...	±0·24	±0·24	

The mean of two measures thus has a probable error $\pm 0''{\cdot}24\times{\cdot}71=0''{\cdot}17$, which satisfies the conditions settled by the Comité Permanent in 1896 May.

11. Each number is derived from five plates. The groups have been selected so as to show any improvement with practice which there may be; and such improvement is in several cases manifest. In this connection it may be interesting to give

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the numbers of "discordances" found among the measures of each observer per 1,000 stars, and the number of stars missed on one occasion and noted on the other. The following numbers are obtained from ten plates each; containing about 2,000 stars generally.

Measurer.	Date.	Discordances per 1000.	No. Missed in D.	R.
B.	Early	50	50	94
B.	Recent	54	47	79
F.	Early	100	69	65
F.	Recent	75	55	75
H.	Early	131	66	60
H.	Recent	64	38	39
C.	Early	79	46	48
C.	Recent	43	44	44
M.	Early	82	71	68
M.	Recent	98	110	77
	General Mean ...	77·6	59·6	64·9

Occultation of Ceres by the Moon on 1897 *November* 13, *visible at Greenwich.*

(*Communicated by the Superintendent of the Nautical Almanac.*)

The following particulars of an occultation of *Ceres*, as visible at Greenwich, are communicated to the Society in the hope that under favourable conditions of weather it may be possible to observe the emersion of the planet; the Moon being 19 days old and the stellar magnitude of *Ceres* being 7·5.

	G.M.T. d	h	m	Angle from North	Vertex.
Immersion	13	10	37	56°	99°
Emersion	13	11	30	312	355

Nautical Almanac Office,
1897 *Sept.* 14.

Catalogue No. 2, *of Nebulæ discovered at the Lowe Observatory, Echo Mountain, California.* By Lewis Swift.

The following list of 25 new nebulæ, follows No. 1 (of 50), discovered at this Observatory and published in *Astronomical Journal* of 1896 November 13, and also in the *Publications of the Astronomical Society of the Pacific.* Since my return to this Observatory in April last, I have devoted my time to searching for comets as well as nebulæ, for which this anomalous climate is so well adapted. The following facts will illustrate its truth. The number of clear nights in 1897 May, were 25. Rainfall 0·87 of an inch. In June, 28, rainfall 0·10. Thus far in July, 26,